

EDOS Data Capture for ALOS

Bruce McLemore¹

Honeywell Technology Solutions / GSFC, Greenbelt, MD 20771, USA

Guy R. Cordier²

ASRC Management Services / GSFC, Greenbelt, MD 20771, USA

Terri Wood³

NASA GSFC, Greenbelt, MD 20771, USA

and

Hårek Gamst⁴

Kongsberg Spacetec AS, Tromsø, Norway

In 2008, NASA's Earth Sciences Missions Operations (ESMO) at Goddard Space Flight Center (GSFC) directed the Earth Observing System Data Operations System (EDOS) project to provide a prototype system to assess the feasibility of high rate data capture for the Japan Aerospace Exploration Agency's (JAXA) Advanced Land Observing Satellite (ALOS) spacecraft via NASA's Tracking and Data Relay Satellite System (TDRSS). The key objective of this collaborative effort between NASA and JAXA was to share science data collected over North and South America previously unavailable due to limitations in ALOS downlink capacity. EDOS provided a single system proof-of-concept in 4 months at White Sands TDRS Ground Terminal. The system captured 6 ALOS events error-free at 277 Mbps and delivered the data to the Alaska Satellite Facility (ASF) within 3 hours (May/June '08). This paper describes the successful rapid prototyping approach which led to a successful demonstration and agreement between NASA and JAXA for operational support. The design of the operational system will be discussed with emphasis on concurrent high-rate data capture, Level-0 processing, real-time display and high-rate delivery with stringent latency requirements. A similar solution was successfully deployed at Svalbard, Norway to support the Suomi NPP launch (October 2011) and capture all X-band data and provide a 30-day backup archive.

I. Introduction

NASA's EDOS has supported Terra science downlinks at White Sands Complex (WSC) since December, 1999. Previous papers have described this multi-mission high-rate system and upgrades to include additions of Aqua, Aura, ICESat, EO-1, and OCO to the mission set (see references 1, 2, 3, 4, 5) preceding ALOS. EDOS recently leveraged the experience from ALOS by successfully supporting the Suomi NPP mission at Svalbard, Norway. Multi-mission support for new missions SMAP, OCO-2, and ICESat-2 is underway at this time.

The ALOS satellite, launched on January 24, 2006 by JAXA, is an Earth Observation mission containing three sensors: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), and the Phased Array type L-band Synthetic Aperture Radar (PALSAR). JAXA and NASA began collaborating in 2007 on an agreement to share ALOS data with NASA in exchange for ALOS use of NASA's Space Network (SN) Tracking and Data Relay Satellite System (TDRSS). ALOS transmitted

¹ GSFO EDOS Project Manager, GSFC/ Code 428, Greenbelt, MD 20771

² Joint Polar Satellite System, C3S Architect, GSFC/ Code 581, Greenbelt, MD 20771

³ EDOS Project Manager, GSFC/ Code 428, Greenbelt, MD 20771

⁴ Senior Electronics Engineer, Kongsberg Spacetec AS, Tromsø, Norway

real-time data using Ka-Band to TDRS F-10 at a rate of 277.52 Megabits per second (Mbps). EDOS was requested to provide and test a prototype system, and, if successful, provide operational support to ALOS.

II. Background

EDOS system core architecture has remained basically the same through today. Figure 1 depicts the distributed functions and data flows. Baseband data is ingested at the stations at downlink rates up to 150 Mbps and the data is rate-buffered via high-rate lines to the EDOS central Level Zero Processing Facility (LZPF) at GSFC. There, various Level-0 products are generated per standards/formats agreed to by the end-users, and distributed to their respective data centers. The data centralization enables the generation of clean, continuous, time-based or session-based data sets. Observation time-based data sets merge telemetry from several supporting ground stations, eliminate duplications and provide a useful format to the science community. Session-based data sets correspond to a spacecraft downlink at a specific ground station.

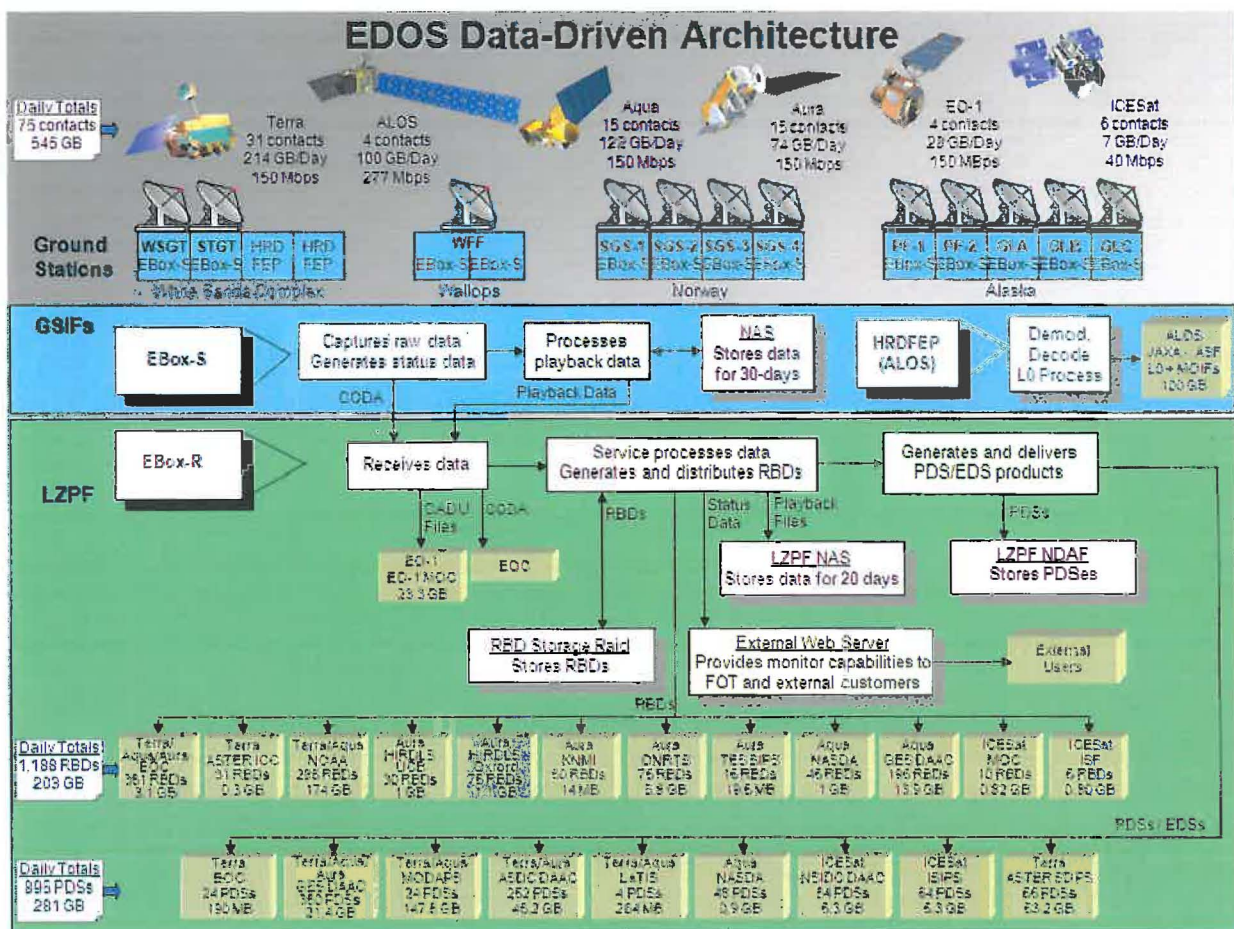


Figure 1. EDOS Multi-Mission Data-Driven Architecture

Several key objectives over the years have been to reduce mission operations costs, increase productivity by enabling automation for nominal operation for all system set-up, data capture, Level-0 data processing and product distribution, and improve product latency to end-users³. The system front-ends are data driven and automatically detect the mission by the spacecraft ID from the telemetry. The spacecraft ID automatically identifies the mission-specific processing configuration to be used. Technology refresh activities have brought uniformity of hardware platform and operating systems across all sites to simplify equipment/system maintenance activities and system security management. EDOS has also deployed a full backup LZPF facility at an alternate location for disaster

recovery. All missions supported to-date conform to the Consultative Committee for Space Data Systems (CCSDS) standards.

III. Architectural Models

EDOS has two operational architectural models: the centralized “legacy” model which collects mission data from multiple ground stations at the LZPF, and the distributed or “remote site decentralized” model, which performs Level-0 processing and delivers data to end-users from the ground station.

A. Centralized Model

The centralized model transmits all data captured at the remote site to the LZPF at GSFC. The LZPF performs Level-0 processing, generates both integrated time-based and session-based near real-time products from multiple ground stations, and delivers all products from GSFC to science customers worldwide.

B. Remote Site Decentralized Model

The decentralized model offers the capability of capturing, processing and delivering the Level-0 data directly to the end-users from the ground site. This approach is only applicable if adequate network bandwidth is available and no multiple-site processing to integrate the data is required. ALOS was the first EDOS mission to make use of the decentralized capability of EDOS.

IV. ALOS Challenge to EDOS

EDOS already had a point of presence at WSC and experience with the SN and TDRS system infrastructure as used for servicing the EOS Terra science data downlinks at 150 Mbps. Using the same infrastructure for ALOS as for Terra (Reference 5), WSC receivers would process the Intermediate Frequency (IF) signal and forward the serial clock and data signals to EDOS Ebox-S for processing.

Two challenges needed to be addressed: First, the ALOS spacecraft used a *Modulo-4* differential encoding scheme and since WSC receivers did not have this capability the EDOS system would have to perform the *Modulo-4* differential decoding. Second, EDOS had to demonstrate an ingest capability and processing at the higher rate of 277 Mbps.

It was also expected that, as EDOS had been operating successfully since 2006 in a data-driven mode of operation (reference 5), autonomous operations would minimize the impact of additional mission support without increasing operations staff.

V. Front-End Configuration and Validation

EDOS worked with the Space Network and supporting organizations to develop end-to-end test approaches. Kongsberg Satellite Services AS (KSAT) and Kongsberg Spacetec AS (KSPT) provided ALOS test data sets consisting of X-band data captured in Tromsø, Norway as part of KSAT’s routine support provided to JAXA’s ALOS data node in Europe.

These data sets were then sourced from GSFC to simulate Ka-band transfer to the TDRS F-10 and downlinks via Ku-band to WSC, in order to prepare and validate the ground systems baseline prior to real-time contacts with the ALOS spacecraft. Refer to Figure 2 below.

The initial testing verified and validated the SN and TDRSS ground network as well the capability of the Ebox-S to perform the necessary processing. However, the unreliability of the serial clock and data signals traversing switches at 277 Mbps suggested use of a backup configuration using a KSPT-provided High Rate Demodulator Front End Processor (HRDFEP) receiver integrating IF signal processing, frame synchronization, product generation, and product distribution. This alternate prototype configuration is also shown in Figure 2 below.

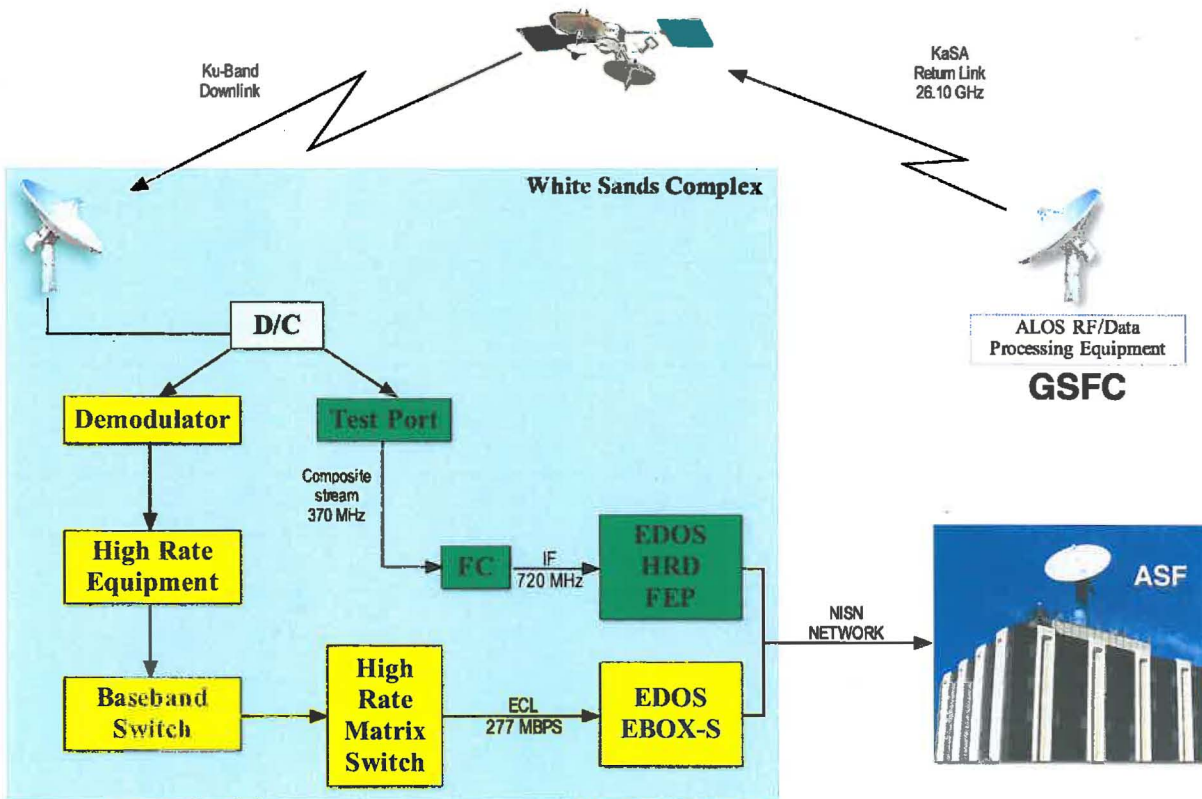


Figure 2. Front-End Configuration and Validation

Both configurations were deployed to support a series of live contacts with the ALOS spacecraft to assess the quality of the space link and of the ground systems. To that effect, six events were scheduled over a two-week period where data would be transmitted from the spacecraft to assess the Bit Error Rate (BER). For all six events, the HRDFEP captured all data error free. The other ground configuration failed the BER quality criteria.

VI. EDOS Requirements for ALOS

After the successful test efforts, JAXA and NASA agreed that EDOS would provide operational support via the IF model using the HRDFEP and the design effort began. The following paragraphs describe the EDOS requirements which drove the EDOS system design and implementation for operational ALOS support:

A. Data Capture and Processing

- 1) The EDOS/ALOS System shall support Data Relay Satellite Communications transmissions (277.52 Mbps real-time downlink rate) at White Sands via the IF signal from the SN for ALOS data.
- 2) The EDOS/ALOS System shall perform Quadrature Phase Shift Keying (QPSK) Demodulation and *Modulo-4* Differential Decoding on the ALOS telemetry.
- 3) The EDOS/ALOS System shall split the I and Q channels for Front End Processing and perform Frame Synchronization, Reed-Solomon (RS) decoding, Pseudo-random Noise (PN) decoding.
- 4) The EDOS/ALOS System shall perform data processing and JAXA Level-0 (JL0) data generation of ALOS PRISM, AVNIR-2, and PALSAR sensor data according to the JAXA specifications.

B. Mission Operation Interface Files (MOIFs)

- 1) MOIF Ingest. The EDOS/ALOS System shall electronically receive and ingest JAXA generated MOIFs (J-MOIFs), via ASF from JAXA. J-MOIFs are required for the generation of Level-0 data.
- 2) MOIF Generation. The EDOS/ALOS System shall generate EDOS MOIFs (E-MOIFs) and transfer the files to ASF. ASF will forward the E-MOIFs to JAXA. The E-MOIFs are required for higher level data processing.

C. Data Delivery Requirements

- 1) The EDOS/ALOS System shall deliver JL0 data to ASF within 2 hours after the end of contact.
- 2) The EDOS/ALOS System shall deliver E-MOIFS data to ASF within 2 hours after the end of contact.
- 3) The EDOS/ALOS System shall deliver JL0 data to JAXA within 4 hours after the end of contact.

VII. EDOS - ALOS Operational System Architecture

The EDOS - ALOS operational system consisted of the following components (see Figure 3 below):

- A. Two IF frequency up-converters (prime and backup) which convert the IF signal from 370MHz to 720MHz.
- B. Two redundant processing and distribution strings:
 - 1) High Rate Demodulator Front End Processor (HRDFEP prime and hot backup)
 - a. High Rate Demodulator performs signal demodulation and differential decoding
 - b. Front End Processor performs Frame Synchronization, RS/PN decoding, and Virtual Channel Data Unit (VCDU)/packet extraction
 - 2) Level-0 Processor (integrated on the HRDFEP)
 - a. Generates and transfers JL0 data and E-MOIF auxiliary files to the NAS
 - 3) Network Attached Storage (NAS) (prime and backup) for data storage of JL0 data, E-MOIFs, and J-MOIFs for 20 days
 - 4) Gateway (prime and backup) for file transfers (both inbound and outbound)
 - a. Receives JAXA-supplied J-MOIFs via ASF
 - b. Transfers JL0 data and E-MOIFs to ASF and JAXA
- C. Redundant switches and firewalls providing a high-rate connection to the NASA Integrated Services Network (NISN) Corporate Network (internet)
- D. EDOS Workstations at GSFC for monitoring and control

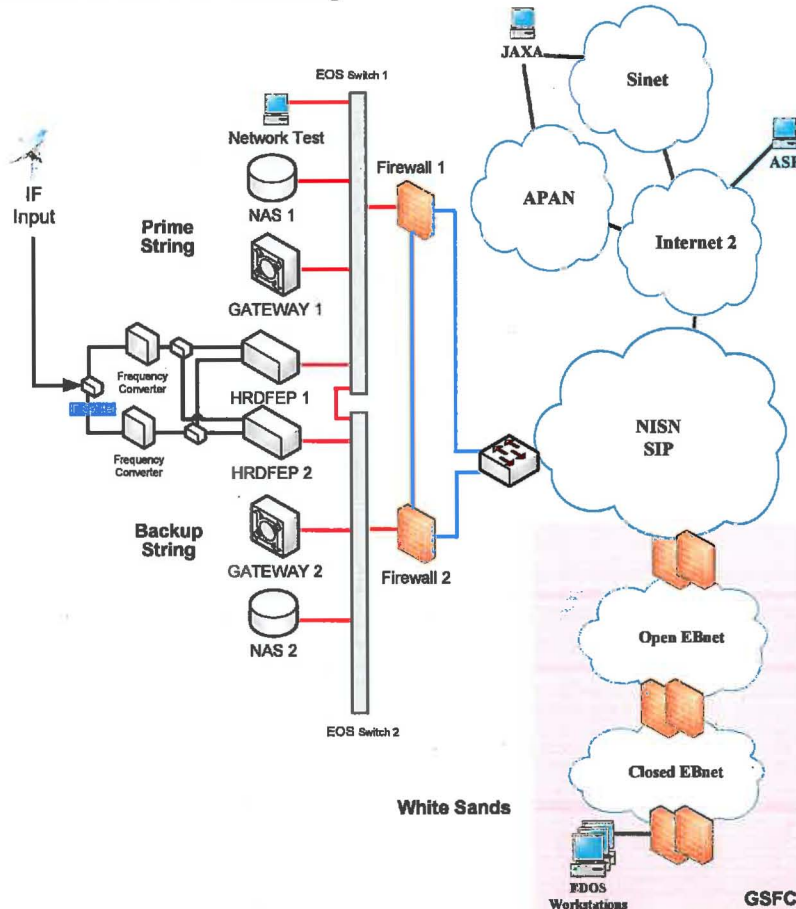


Figure 3. EDOS Operational System for ALOS

VIII. EDOS Operational Concept for ALOS

EDOS Operations is staffed 24x7 providing operational support for all EDOS missions. ALOS support was provided with no additional staffing and consisted in the following responsibilities:

- Verify receipt of all J-MOIFs from ASF before the scheduled contacts.
- Monitor TDRS/ALOS contact by verifying IF signal and data quality for all segments.
- Monitor Level-0 processing for each segment, including E-MOIF auxiliary files generation.
- Verify all data file transfers to ASF and JAXA.

IX. ALOS High-Rate Data Capture and Level-0 Processing

A. Design Goals

EDOS wanted the ALOS data capture system to reflect the same operational principles and philosophy as applied in the EOS ground system. The following key design goals assigned to this task were:

- Reliability based on the heritage from the very mature EOS system
- Data driven operations to allow the system to operate nominally without manual intervention
- Graphical User Interface (GUI) interface for monitoring and control capabilities
- Real-time data processing as applicable to reduce latencies and minimize end-to-end delays
- Flexibility to further enhance the system solution based on ALOS project's requirements

B. ALOS HRDFEP System Capabilities

For the initial ALOS/TDRSS testing, a standard Multi-Mission Earth Observation System (MEOS) Capture HRDFEP was used as receiver and data capture system. For the operational system, Kongsberg Spacetec AS developed an ALOS Level-0 processor and integrated it on the HRDFEP.

In its final operational stage, the MEOS Capture HRDFEP included the following functions:

- A high rate demodulator
- Front End Processor (FEP)
- Local data storage
- Level-0 data generation per JAXA specifications
- Browse image generation per JAXA specifications
- JPG image generation
- Real-time Quick Look image generation and display
- Real-time image projection into Google Earth display
- System GUI

C. Data Storage

A redundant Network Attached Storage (NAS) was used to store and archive data in the ALOS system at the White Sands ground station. The NAS storage was used as a local file repository in the ALOS system. Incoming and outgoing files were exchanged between the Gateway and the HRDFEP via the NAS.

D. Demodulator

Demodulation was standard QPSK with *Modulo-4* differential decoding for ambiguity resolution. The demodulated data was virtually error free, offering very high and very stable data quality. Although indications of some signal distortion was observed in the I/Q vector diagram, this distortion was very stable and never affected the data quality.

E. Front-End Processor (FEP)

FEP processing included splitting the I and Q channels, frame synchronization, de-randomization and Reed-Solomon (255, 223) decoding. Two FEP channels were used for the I and Q channel data, respectively. These data streams were stored to files and re-combined for Level-0 processing and image generation. Ingested and decoded data were stored as files in a local file archive in the HRDFEP. Data were simultaneously written to and read from these files to enable real-time Level-0 data generation. The ingested files were also copied to the NAS data archive.

F. HRDFEP GUI

The HRDFEP GUI shown below in Figure 4 depicts the demodulator and FEP views. As can be seen in the Input Channel sub-windows, the numbers of uncorrectable frames in the FEP channels are 81 and 33, respectively. These are the number of uncorrectable frames seen during demodulator lock-in. After demodulator lock the number of bit errors is 0 for both channels, indicated by the "R-S corr" status indicator. Approximately 7 million frames have been captured at the time shown.

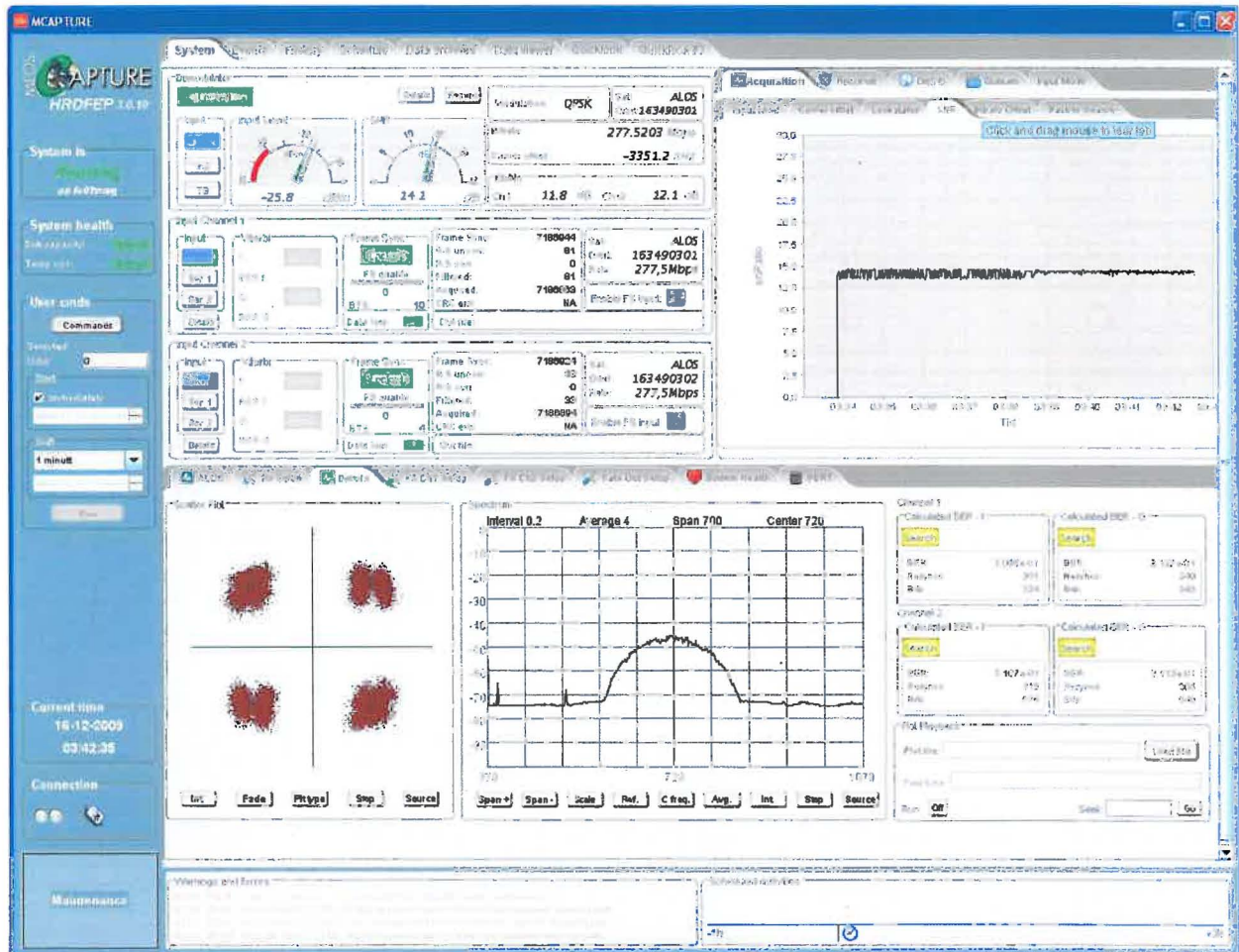


Figure 4. HRDFEP GUI Display for ALOS

G. Level-0 Data Generation

To shorten the total system delays, from data capture to products delivery, the Level-0 products were generated in real-time during data capture. The Level-0 processing speed was sufficiently high to keep up with the data capture at 277 Mbps, constantly lagging behind by only a few seconds. This meant that the Level-0 products were completed as the data downlink completed. Transfer of the generated data started immediately after the pass was completed, hence there was no additional delay associated with the Level-0 processing itself.

Level-0 generation used a number of J-MOIFs received from JAXA via ASF. The J-MOIFs were received by the Gateway and stored on the NAS for use by the HRDFEP. E-MOIFs were generated or updated as part of the Level-0 processing. J-MOIF files were used for further processing of higher level products at JAXA and ASF. These files were generated and exported to the NAS as the final stage of the Level-0 processing, after which they were sent to ASF using the Gateway.

Browse images were defined as part of the Level-0 generation. Browse image files were generated from the captured data to offer end users a view into the data contents. These image files were generated from JAXA specifications. In addition to the specified Browse images, the HRDFEP also generated versions of these image files in JPEG format. This was done for practical purposes because of the widespread use of the JPEG file format.

An example browse image (St. Petersburg, Florida, USA) is shown in Figure 5 (to the right):



Figure 5. ALOS PRISM Browse Image
Image provided courtesy of JAXA

H. Google Earth Views

For educational purposes and to visualize the satellite's operation, it was decided that KSPT would develop and integrate a separate tool in the HRDFEP to project real-time generated images into Google Earth. When a data downlink from ALOS started, Google Earth was pointed at the relevant geographical area. As data was processed into Browse images, the JPEG versions of the images were projected into the wider Google Earth image. The user could then observe the geographical coverage of the instrument, the data quality, and how well the generated image mapped into the area stored by Google Earth, with its local details and contours.

I. Data Reprocessing

For potential situations where a set of Level-0 data products was not generated with the expected quality, completeness and correctness, a reprocessing capability was developed. The operator would select a data set from the archive via a tool in the GUI and initiate reprocessing of the data into Level-0 products, using archived ingest data files and J-MOIFs as input. During the operational phase the need for reprocessing a data set was never experienced due to the redundant design of the system.

J. Data-Driven Operation

The MEOS Capture HRDFEP supported two operational modes: A conventional, *i.e.* commanded or schedule driven mode, and a data driven mode. In the data driven mode, operations were fully autonomous, *i.e.*, without needing any kind of operator control or intervention whatsoever. The data driven mode was used in the operational system.

K. Quick Look Views

The HRDFEP provided real-time data image displays for the AVNIR-2 and PRISM instruments. Visible images were generated from the captured data stream and displayed in real-time as data were ingested. This provided the operator a direct view of the data contents and quality. An example AVNIR-2 quick look view is shown in Figure 6.

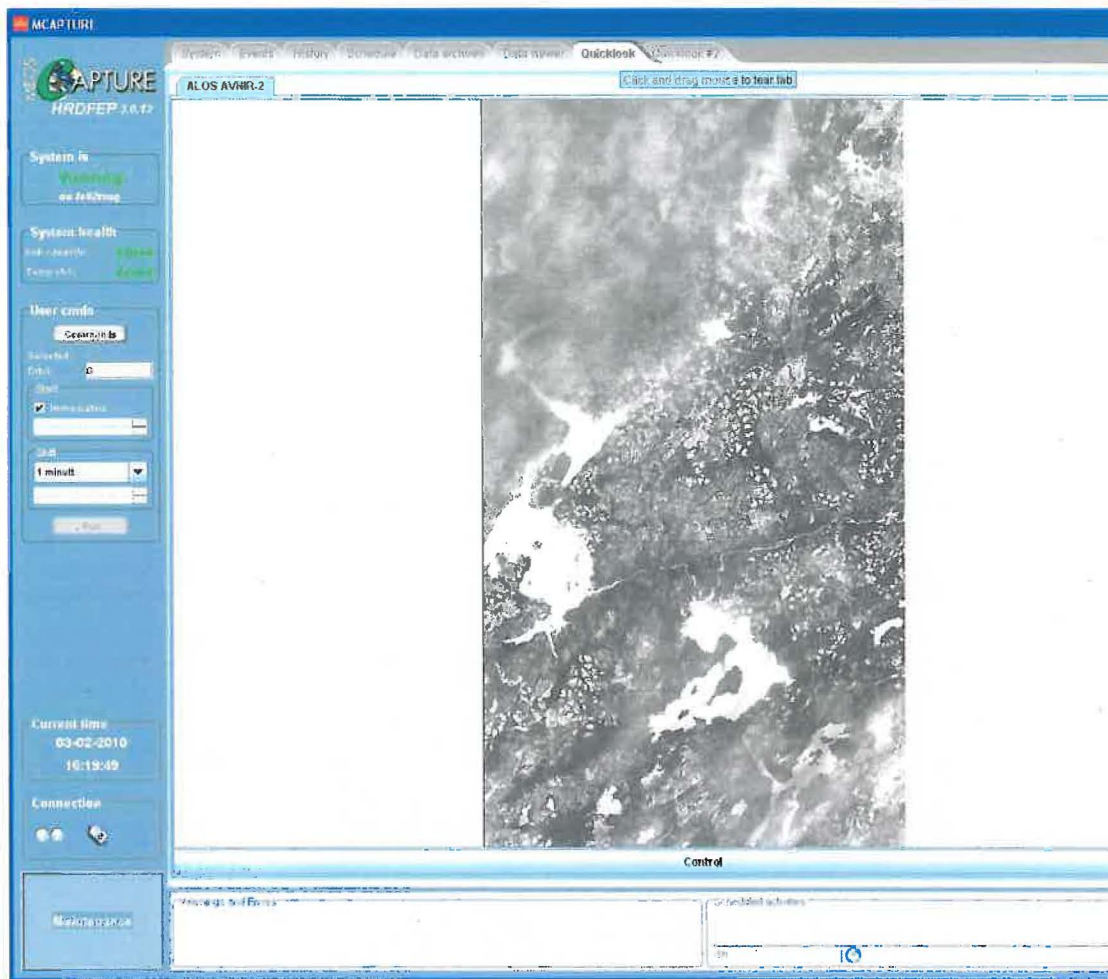


Figure 6. ALOS Quick Look View

X. ALOS High-Rate Data Delivery

EDOS normally uses a TCP/IP stream to deliver science data from the ground station. However, for ALOS, the stringent latency requirements, length of the TDRSS passes, volume of data for each downlink, and the round trip delays from White Sands to JAXA and ASF made TCP delivery difficult.

Instead, the Aspera User Datagram Protocol (UDP)-based Wide Area Network (WAN) accelerator software (proposed by JAXA) was used with Aspera clients installed on the EDOS Gateways to support high-rate transfers to Aspera servers located at ASF and JAXA. As soon as the ALOS pass was complete, concurrent 100 Mbps high-rate transfers to JAXA and ASF were initiated by the Gateway (see Figure 7). The Gateway reads the new Level-0 files from the NAS and transfers them to ASF and JAXA after first generating a tar file of the Level-0 data. Aspera consistently maintained a high level of performance at a very steady rate, while protecting the data with encryption during the transfers.

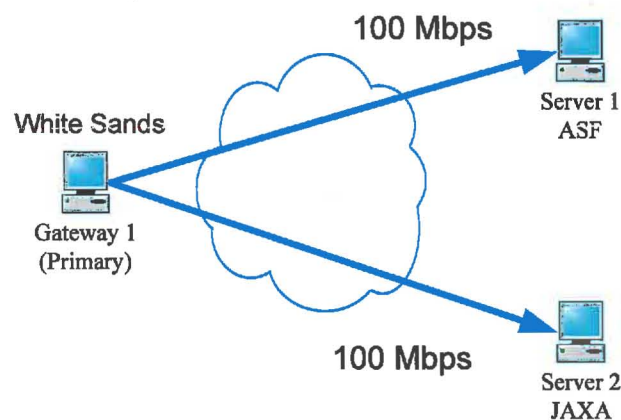


Figure 7. Aspera Configuration for ALOS from White Sands

XI. Lessons Learned from ALOS Support

The EDOS systems flexibility was amply demonstrated with ALOS where a working solution was deployed in a few months under a modest budget. The design, implementation, and testing of the operational ALOS system as well as its daily operations was an effort that presented a variety of challenges to the EDOS project team. All were surmounted and many have generated lessons learned that can be applied to other missions where they can help avoid system development impacts and impaired operations. The highlights are listed as follows:

- Requirements need to be clearly defined, reviewed, and documented prior to system implementation. Face-to-face technical interchange meetings between NASA and JAXA engineers were invaluable.
- “Best Effort” approaches to both system development and operations need to be clearly defined. Early completion of Memorandum of Agreements (MOAs) and Operational Agreements (OAs) is recommended.
- Working closely with an international partner on an aggressive schedule is quite possible and was successfully demonstrated on ALOS with the close team relationship between EDOS and Kongsberg Spacetec.
- EDOS successfully implemented system architectural concepts that have expanded EDOS capabilities and system flexibility that can be applied to other missions.
- Kongsberg successfully developed and integrated new Front-End technologies and verified their effectiveness for ALOS and other missions, confirming the value of identifying and applying new technology.
- The modular architecture of the EDOS system supported the rapid addition of the ALOS mission and can be applied to other missions as well, as demonstrated recently with Suomi NPP.
- EDOS systems and its operational staff demonstrated the efficiencies and effectiveness of a multi-mission science processing operations center staffed 24x7 supporting new missions without additional staff.

XII. Conclusion

EDOS began operational support of ALOS in April, 2010, and provided continuous operations until April, 2011 when the ALOS mission ended. EDOS successfully captured approximately 1,460 ALOS passes and processed approximately 36.5 Terabytes of data during the one-year operational period. Last year, EDOS was asked to implement a system to capture all Suomi NPP science data and provide a 30-day backup archive at Svalbard. Within a short period, EDOS reused a configuration similar to ALOS to service NPP with IF input. The HRDFEP has successfully captured all passes since launch in a data-driven mode of operation. During an extended network communication outage between Svalbard and GSFC, the EDOS data-driven HRDFEP safely captured all the science data autonomously with no operator intervention.

Acknowledgments

The authors wish to express their appreciation to the support of the ALOS staff at JAXA and ASF, and the support and leadership of the NASA GSFC civil servants and contractor personnel from the ESMO organization that contributed to this program and still do. A special mention of appreciation is extended to the Mission Operations and Management Services (MOMS) EDOS support team at GSFC and to the Kongsberg Spacetec team of Tromsø, Norway for their professional services and technical support.

The contractor support for the work described in this paper was provided under the Honeywell Technology Solutions, Inc. (HTSI) Mission Operations and Mission Support contract # NNG04DA01C with NASA.

References

- ¹Cordier, G. R., Gomez-Rosa, C., Knoble, G. G., McCaleb, Fred W., “EOS Operations Systems: Planned and Proposed Changes to Reduce Operations Costs,” *Proceedings of the 6th International Symposium on Reducing the Costs of Spacecraft Ground Systems and Operations*, SP-601, ESA, 2005
- ²Cordier, G.R., Gomez-Rosa, C., Knoble, G. G., McCaleb, Fred W., “Autonomous multi-missions, multi-sites X-band data capture systems,” *SpaceOps 2006 Conference*, Rome, Italy
- ³Cordier, G.R., Gomez-Rosa, C., McLemore, B., “EOS Operations Systems: EDOS Implemented changes to reduce Operations Costs,” *Proceedings of the 7th International Symposium on Reducing the Costs of Spacecraft Ground Systems and Operations*, SP-xxxx, ESA, 2007
- ⁴Cordier, G. R., Wilkinson, C., C., McLemore, B., “Web monitoring of EOS front-end ground operations, science downlinks and Level-0 processing,” *SpaceOps 2008 Conference*, Heidelberg, Germany
- ⁵Cordier, G. R., McLemore, B., Wood, T., Wilkinson, C., “EDOS role in NASA current and future Earth Sciences Missions,” *SpaceOps 2010 Conference*, Huntsville, Alabama, USA